Development of Methods for Determining Airport Pavement Marking Effectiveness

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March 2003

DOT/FAA/AR-TN03/22

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16. Abstract

Paint markings on runways, taxiways, and ramps play an important role in preventing runway incursions. Paint markings, however, deteriorate in terms of their conspicuity and must be replaced over time. Presently, the conspicuity is determined by visual inspections of segments of these markings, but the validity of these inspections cannot always be confirmed.

This study was undertaken to develop a method for a quick and accurate evaluation of paint markings. A manual method was required for eliminating subjectivity in the current method, and an automated method was developed for evaluation of larger surface markings over a vast airport area. In addition, the study also established a threshold pass/fail limit for white and yellow paint.

It was found that for the manual method, three devices are required: (1) a retro-reflectometer is required for determining retro-reflectivity of the beads, (2) a spectrophotometer is required to determine whether or not the paint marking has faded out of tolerance, and (3) a transparent grid is used to determine coverage of the paint. If any one of these three tests fails, the pavement marking fails.

For the automated method, a van-mounted Laserlux or similar mobile unit is required. The automated method increases the speed and sample size. It works well for large airports, which have very long runway centerlines and threshold markings.

The retro-reflective threshold limit for yellow paint is 70 mcd/m²/lx and for white paint 100 mcd/m²/lx. The coverage threshold pass/fail limit is 50%.

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EXECUTIVE SUMMARY

The Federal Aviation Administration, Office of Aviation Research, Airport Technology Research and Development Branch, AAR-410, has developed methods and/or equipment intended to facilitate the determination of airport pavement marking effectiveness and to establish standards by which the need for reapplication or restoration may be measured. Paint markings on runways, taxiways, and ramps play an important role in preventing runway incursions. Paint markings, however, deteriorate in terms of their conspicuity and must be replaced over time. Presently, the conspicuity is determined by visual inspections of segments of these markings, but the validity of these inspections cannot always be confirmed.

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INTRODUCTION

The project to develop methods and/or equipment intended to facilitate the determination of airport pavement marking effectiveness and to establish standards by which the need for reapplication or restoration may be measured was undertaken by the Airport Technology Research and Development (R&D) Branch, AAR-411, in response to a request from the Federal Aviation Administration (FAA) Office of Airport Safety and Standards, Director, AAS-1. The project develops a repaint criterion to assist the Airport Safety and Operations Division, AAS-300, in the revision of advisory circulars concerning when to repaint pavement markings on an airport. The work involved developing a manual method, an automated method, and threshold limits for pass/fail determination.

OBJECTIVE.

This effort was directed specifically toward three objectives by which airport operators can evaluate pavement markings.

- Develop a manual method for the objective evaluation of airport surface markings.
- Develop an automated method to evaluate large surface markings over a vast airport area in a timely manner.
- Establish threshold limits for white and yellow paint for a pass/fail criterion of the pavement markings.

RELATED DOCUMENTS.

Related documents dealing with this evaluation project are:

- DOT/FAA/CT-94/119, "Evaluation of Alternative Pavement Marking Materials," January 1995.
- DOT/FAA/CT-94/120, "Evaluation of Retro-Reflective Beads in Airport Markings," December 1994.
- DOT/FAA/AR-TN96/74, "Follow-On Friction Testing of Retro-Reflective Glass Beads," July 1996.
- NBSIR 75-663, "Color Requirements for the Marking of Obstructions," March 1975.
- International Civil Aviation Organization (ICAO) Annex 14 Volume I, Appendix 1, "Colours for Aeronautical Ground Lights, Markings, Signs, and Panels ," July 1999.

BACKGROUND

Painted markings on runways, taxiways, and ramps play an important role in preventing runway incursions. However, currently, there is no method available to objectively analyze the conspicuity of pavement markings. The most prevalent method of applying pavement markings on airport runways and taxiways is by the use of paint or epoxy materials containing reflective beads to enhance performance. Industry has developed test equipment to determine the retro-reflectivity values of glass beads in marking materials for both portable spot testing and mobile testing of paint markings.

At present, the effectiveness or satisfactory performance of the marking material is determined principally by ground observers making visual inspections of segments of markings. Their subjective evaluation of marking effectiveness is influenced by a number of factors including, but not limited to, the following:

- Weather conditions under which the inspection is made.
- Traffic to which the inspected segment is subjected to over time.
- Personal opinion of the inspector as to what constitutes satisfactory condition or performance.

The many variables in a subjective technique for evaluating markings can lead to a lack of confidence in the validity of the evaluation. Furthermore, an objective method would provide the consistency that subjective methods do not provide.

In some instances, airport marking deficiencies have been brought to the attention of the local authorities, with varying results. Here again, the evaluation is based on subjective opinion alone.

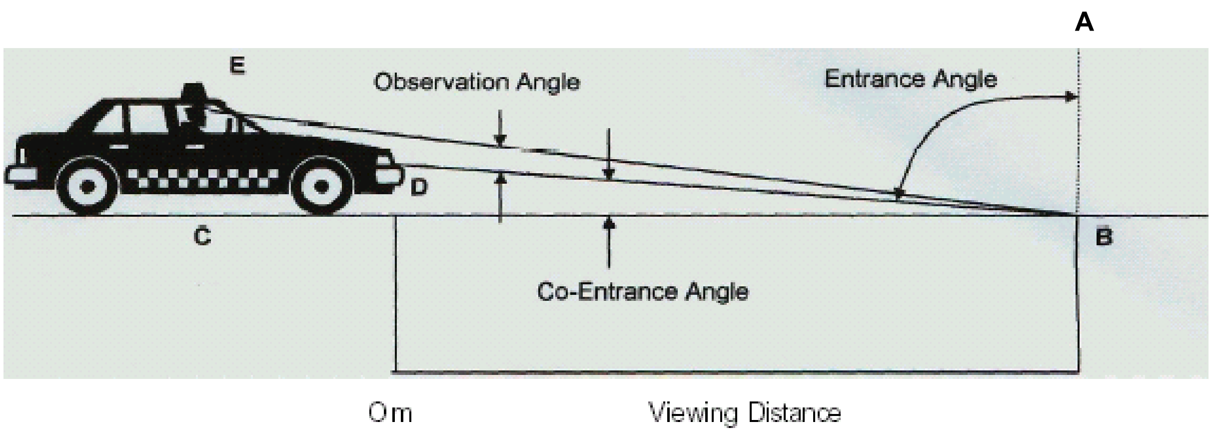
It is highly desirable that methods for accurately and quickly determining the true effectiveness level of airport markings be developed and disseminated to the field. Therefore, a manual method and an automated method needed to be developed. The manual method was developed to reduce subjectivity in the inspection of paint markings. The automated method was developed to provide a quicker evaluation of paint markings at large airports.

EVALUATION

An initial survey was done to obtain information and suggestions from user groups relating to methods and techniques used in the past and present to conduct evaluations of pavement markings. Organizations that were contacted comprised of the Airport Certification Staff in the FAA regional offices and State and National Highway Maintenance Organizations. From these contacts it was shown that one can determine the retro-reflectivity of beads by using a retro-reflectometer, can obtain the chromaticity from a spectrophotometer, and can determine the coverage with a transparent grid.

RETRO-REFLECTOMETER EVALUATION.

Three 30-meter geometry retro-reflectometers were evaluated to determine their effectiveness (LTL-2000, MX30, and MP-30). It was determined that all the retro-reflectometers tested were adequate, but the LTL-2000, manufactured by Delta Light & Optics, was chosen for this evaluation because it has traceability to a reference standard in Denmark. The National Institute of Standards and Technology does not have a reference standard for retro-reflectometers. The 30-meter geometry for retro-reflectivity (which is distance from the headlights to the pavement markings) is the standard used by the highway departments (see figure 1).



Angle ABD = Entrance Angle = 88.76 degrees
Angle CBD = Co-Entrance Angle = 1.24 degrees
Angle DBE = Observation Angle = 1.05 degrees

FIGURE 1. THIRTY-METER GEOMETRY MEASUREMENT FOR RETRO-REFLECTIVITY

SPECTROPHOTOMETER EVALUATION.

A thorough evaluation of spectrophotometers, which measures chromaticity, was performed. The technical group that handles color standards is the International Commission of Illumination (CIE). The CIE developed the methodology for describing and tabulating colors in a numerical system that is based upon a standard observer. The standard observer is defined by small groups of individuals (about 15-20) that have normal human color vision. The specification uses a technique to match colors to an equivalent red, green, and blue (RGB) tristimulus value.

An individual views a split screen with 100% reflectance (that is, pure white). On one half, a test lamp casts a pure spectral color on the screen. On the other half, three lamps emitting varying amounts of red, green, and blue light attempt to match the spectral light of the test lamp. The observer views the screen through an aperture and determines when the two halves of the split screen are identical. The RGB tristimulus values for each distinct color are obtained this way.

The chromaticities are expressed in terms of the standard observer and coordinate system adopted by the International Commission on Illumination (CIE) at its Eighth Session at Cambridge, England, in 1931. The 1931 observer had a 2˚ field of vision (i.e., the amount taken in by the fovea alone). This methodology reduces the spectral emission characteristics of a source to a three-letter designation with associated numbers. This designation system enables quantitative measurements of physical sources of color. The CIE units discussed here are CIE Yxy. Where Y is the absolute measure of the visual luminance of the source and x and y are the chromaticity coordinates. The spectral data is converted to chromaticity coordinates and plotted on a CIE chromaticity chart, shown in figures A-1 and A-2 in appendix A.

MANUAL METHOD. The pavement markings were evaluated in three ways:

1. By checking the retro-reflectivity with a retro-reflectometer (beads).

2. By checking the chromaticity with a color-guide device (paint).

3. By visually inspecting the uniformity of coverage of the entire paint marking using a transparent grid (paint).

Retro-Reflectivity Check. Conduct the evaluation with a retro-reflectometer by aiming the device at a pavement marking, which has beads, and taking a reading. This step should be skipped in the event that the pavement marking does not have beads. Six readings should be taken across the markings, three in each direction to assure uniformity of the line. The readings should be at the beginning, middle, and end of the paint marking, then reverse direction and take them again at the beginning, middle, and end of the pavement marking. For pavement markings 120 feet or longer, six readings should be taken every 100 feet. For pavement markings 120 feet or less, six readings should be taken. The six readings should then be averaged to get the retro-reflective reading. Follow the steps below to take the readings of the pavement markings.

1. If this is the first time the retro-reflectometer is being used, refer to the user manual for the setup of the device.

2. Check the calibration of the retro-reflectometer.

3. Take the first reading at the beginning of the pavement marking and record the reading.

4. Take the second reading at the middle of the pavement marking and record the reading.

5. Take the third reading at the end of the pavement marking and record the reading.

6. Turn the retro-reflectometer around to take readings in the opposite direction.

7. Take the fourth reading at the beginning of the pavement marking and record the reading.

8. Take the fifth reading at the middle of the pavement marking and record the reading.

9. Take the sixth reading at the end of the pavement marking and record the reading.

10. Add up all the data points and divide by six and record the average.

Chromaticity Check. Evaluate the pavement marking for chromaticity with a spectrophotometer by aiming the device at the pavement marking and checking the color against a CIE standard illuminant D_{65} (unbeaded and beaded retro-reflective paint) chromaticity chart, for at least three locations on the pavement marking. The readings should be taken at the beginning, middle, and end of the pavement marking. If the pavement marking readings are outside the lines on the chromaticity chart, it will be considered failed. (See figures A-1 and A-2 in appendix A for the two D_{65} chromaticity charts). Follow the steps below to take the readings of the pavement markings.

1. If this is the first time the spectrophotometer or chromaticity device is being used, refer to the user manual for the setup of the device.

2. Check the calibration of the chromaticity device.

3. Take the first reading at the beginning of the pavement marking making sure that the device is fully on the pavement marking. (Do not tip device.) Record the data coordinates.

4. Take the second reading at the middle of the pavement marking. Record the data coordinates.

5. Take the third reading at the end of the pavement marking. Record the data coordinates.

6. Graph the three data points obtained above. For unbeaded readings, use figure A-1 with ordinary colors for surface markings. For beaded readings, use figure A-2 with colors of retro-reflective materials for markings, signs, and panels.

Coverage Check. This inspection will ensure uniformity of coverage of the entire line, such as paint cracking, peeling, and whether or not the marking has adequate coverage. One-square-inch sections of transparent material inscribed within a grid of 100 equal squares shall be used as a tool for quantitative measure of specified percentage of coverage. The grid concept was taken from the Air Force who used it for measuring rubber coverage on pavement. For a 6-inch line, it is suggested that a grid of 5 x 20 inches be used, and for a 12-inch line, a grid of 10 x 10 inches. Count the squares that have no paint, e.g., 3 out of 100 squares equal 3% of the paint gone or 97% coverage, see figures 2 and 3.

FIGURE 2. A 5- x 20-inch GRID FOR A 6-inch LINE

FIGURE 3. A 10- x 10-inch GRID FOR A 12-inch LINE

Follow the steps below to take the readings of the pavement markings.

1. Using either the 10- x 10-inch grid or the 5- x 20-inch grid, place the grid on the line to be evaluated.

2. Count the squares that have no paint.

3. The number of squares without paint will be the percentage of paint gone. In other words, if there are 30 out of 100 squares that have no paint, then 30% of the paint is gone.

With these three evaluations, a determination of whether or not the paint marking passes or fails can be made. If the readings for any one of the three tests (the chromaticity, retro-reflectivity, or percentage of coverage) fail, it is an automatic failure of the pavement marking.

<u>AUTOMATED METHOD—VAN-MOUNTED RETRO-REFLECTIVE CHECK</u>. The automated inspection system increases the speed and sample size. The automated inspection system has the following objectives:

- Evaluate the complete, or entire, painted marking configuration (i.e., inspection of the full length of runway centerline markings).

- Accomplish the evaluation within a limited time frame (i.e., minimal runway downtime availability).

- Take contrast with adjacent surfaces (i.e., concrete, asphalt, or black paint) into account.

- Discriminate between reflective beaded surfaces and nonreflective, nonbeaded surfaces.

All known manufacturers of a van-mounted retro-reflectometer were contacted for a briefing on their equipment. From this effort, a van-mounted Laserlux was chosen to perform this portion of the test (see figure 4). Software modifications had to be made in order to accommodate an airport environment. These modifications included changing the distance measuring instrument software from 100- to 10-ft station intervals. The Laserlux has an accuracy of ±15%, whereas the manual LTL-2000 retro-reflectometer has an accuracy of ±5%.

The equipment needed to perform a van-mounted retro-reflective check, is a computer, a printer, and a video camera.

A laser retro-reflectometer could be mounted to a friction test vehicle, but a van-mounted laser retro-reflectometer seems to be the best approach since the laser retro-reflectometer is very difficult to align properly when mounted with other equipment such as a friction test vehicle. Also there is not enough room in the friction test vehicle for the computer and printer.

Paint markings were checked at the Atlantic City International Airport. The areas checked were (1) movement area marking at taxiway J and the FAA ramp, (2) taxiway holding position line at taxiway J and Bravo, (3) runway holding position line at taxiway B, (4) threshold lines,

(5) centerline on runway 4/22, (6) threshold lines, and (7) centerline on runway 13/31. At each of these locations, the paint markings were evaluated for black background contrast, the chromaticity, the van-mounted retro-reflectivity, and then validated by hand with an LTL-2000. The paint markings going across the taxiways and runways were driven across rather than down the taxiway or runway (which would be the normal direction of travel). See appendix A, figures A-3 and A-4, for data and graphs showing examples of the data format provided by the van.

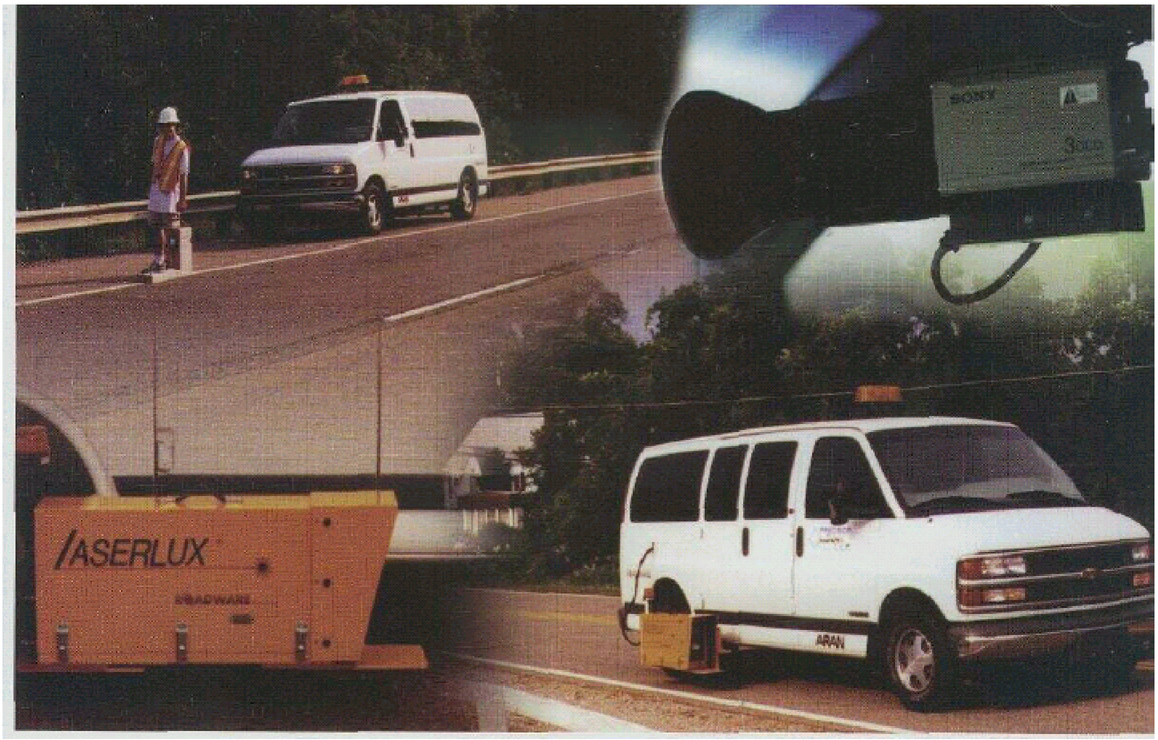


FIGURE 4. VAN-MOUNTED RETRO-REFLECTOMETER

REPAINT CRITERIA IDENTIFICATION. In order to use the retro-reflective readings for evaluation, a pass/fail threshold limit needed to be established for yellow and white pavement markings. Several DOT organizations and the Federal Highway Administration (FHWA) were consulted. Through these communications, it was learned that the retro-reflective values of 70 mcd/m^2/lx for yellow paint and 100 mcd/m^2/lx for white paint are in the process of being accepted for the failure limits of yellow and white pavement markings in project TE-29 of the FHWA. The AAR-411 group proceeded to validate these failure limits above and below 70 mcd/m^2/lx for yellow and above and below 100 mcd/m^2/lx for white at three locations. Night testing was performed on newer hot-mix asphalt, Portland cement concrete, and old hot-mix asphalt to confirm whether or not these two failure limits were accurate.

For the new hot-mix asphalt site, 12 participants were asked to do a subjective pass/fail evaluation of selected lines. For the Portland cement concrete at taxiway Hotel and the old hot-mix asphalt at taxiway Delta, only three participants evaluated the selected lines due to heighten security on the airport. The results were compared to the objective measurement taken, as shown in tables 1 and 2. Each line was selected based on its retro-reflectivity at the time. The idea was to use lines with retro-reflectivity in the 70 mcd/m^2/lx range for yellow and in the 100 mcd/m^2/lx range for white. Looking at table 1, for line 66, the retro-reflective reading was 61 mcd/m^2/lx with no one passing the line and 12 people failing the line. For line 111, the retro-reflective reading was 86 mcd/m^2/lx with three people passing the line and no one failing it.

TABLE 1. YELLOW PAVEMENT MARKINGS

New Hot-Mix Asphalt Test Section				Taxiway Hotel on Portland Cement Concrete				Taxiway Delta on Old Hot-Mix Asphalt			
Line No.	Retro-Reflectivity			Line No.	Retro-Reflectivity			Line No.	Retro-Reflectivity		
		Pass	Fail			Pass	Fail			Pass	Fail
49	79	5	7	65	64	0	3	89	66	1	2
66	61	0	12	25	88	2	1	90	69	2	1
44	71	4	8	47	69	1	2	111	86	3	0

TABLE 2. WHITE PAVEMENT MARKINGS

New Hot-Mix Asphalt Test Section				Taxiway Hotel on Portland Cement Concrete				Taxiway Delta on Old Hot-Mix Asphalt			
Line No.	Retro-Reflectivity			Line No.	Retro-Reflectivity			Line No.	Retro-Reflectivity		
		Pass	Fail			Pass	Fail			Pass	Fail
116	68	0	12	93	76	0	3	36	94	2	1
119	88	2	10	95	123	0	3	95	122	1	2
9	131	9	3	51	109	3	0	114	109	1	2

Looking at table 2, for line 116, the retro-reflective reading was 68 mcd/m^2/lx with no one passing the line and 12 people failing the line. For line 51, the retro-reflective reading was 109 mcd/m^2/lx with three people passing the line and no one failing it. Figure 5 shows the night evaluations, which collected the data for the charts above.

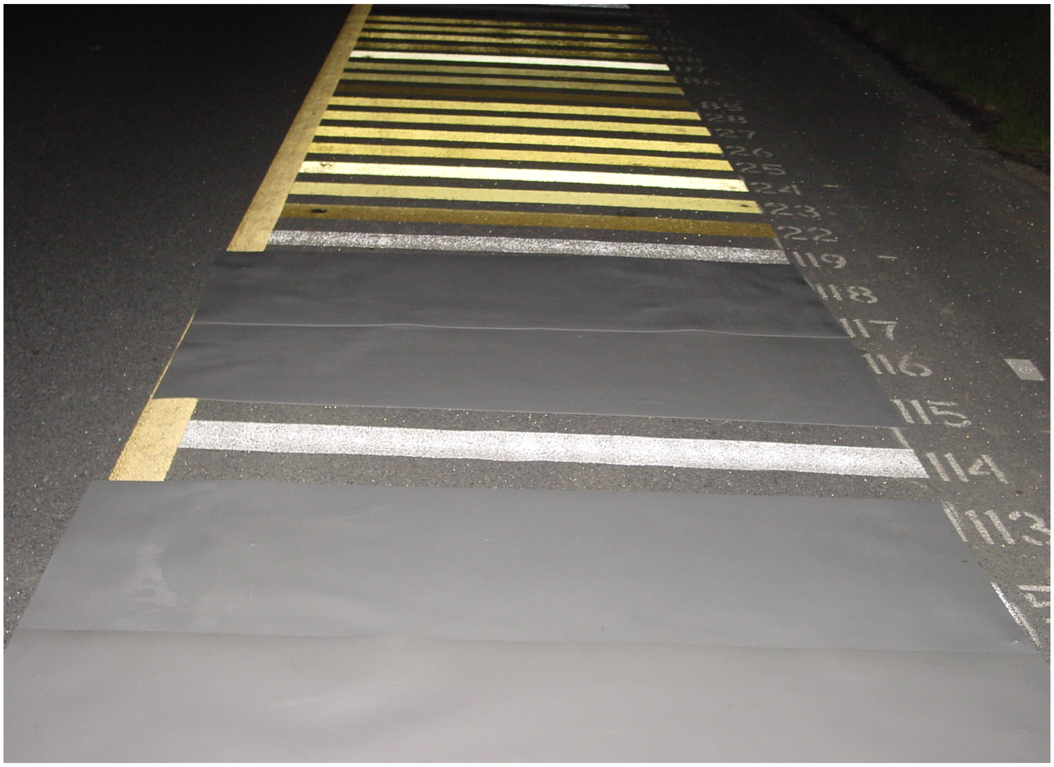


FIGURE 5. PAVEMENT MARKING EVALUATION LAYOUT

<u>Threshold (Pass/Fail) Limits for Chromaticity of Yellow and White Pavement Markings</u>. A representative from the FHWA was contacted concerning the chromaticity or color pass/fail limits to be used for the spectrophotometer. A 3-year evaluation of faded yellow pavement markings began in October 2002. The International Civil Aviation Organization (ICAO) was also contacted, and they recommended that the CIE D_{65} chart boundaries be adhered to. The problem with adhering to the CIE D_{65} chart boundaries for ICAO yellow is that most of the yellow pavement markings will fail both initially and over time. The FAA boundaries for aviation yellow are not the same as for ICAO yellow. Even the FAA boundaries for aviation yellow will not work because the data points obtained will be outside of the FAA boundaries. Therefore, an evaluation of the initial and over time chromaticity readings were compiled. The resulting region for FAA in-service yellow is shown in figures A-1 and A-2 in appendix A. For an in-depth discussion of how the FAA in-service yellow was obtained, see figure A-5 in appendix A. The region for white will be the ICAO white region, there was no need to change this region.

If a yellow data point crosses over the FAA in-service aviation yellow region, then the data point will be considered failed. If a white data point crosses over the ICAO white region, then it will be considered failed.

<u>Threshold (Pass/Fail) Limit for Paint Coverage</u>. The threshold pass/fail limit for coverage will be determined by the use of a transparent grid. The failure limit was determined to be 50% by talking with inspectors and analyzing pavement markings. At this percentage, the pavement marking becomes difficult to decide what it is trying to represent.

PROJECT PARTICIPANTS.

Inspectors from the field were asked to evaluate the manual technique procedures. Individuals from the AAR-411 organization, along with contract support personnel, participated in the manual technique evaluation and coordinated the effort required at the William J. Hughes Technical Center and the Atlantic City International Airport on the automated method for repaint criteria. They were also responsible for the collection of the data, analysis of the results, and preparation of this report.

EQUIPMENT REQUIREMENTS.

The following equipment was used for testing:

- Hand-held portable retro-reflectometer, 30-meter geometry (LTL-2000)
- Van-mounted Laserlux, 30-meter geometry mobile laser retro-reflectometer
- Spectrophotometer, chromaticity meter (Color-Guide P/N 45º/0º)
- Vehicle for ground control support of the van-mounted Laserlux

All testing was performed at the FAA William J. Hughes Technical Center and at the Atlantic City International Airport, Atlantic City, New Jersey, on a new hot-mix asphalt test section, taxiway Hotel on Portland cement concrete, and taxiway Delta on old hot-mix asphalt.

RESULTS

MANUAL METHOD.

For the manual method, it was determined that three checks (retro-reflectivity (beads), chromaticity or color (paint), and coverage (paint)) should be performed to adequately evaluate pavement markings.

Conversations with the inspectors, DOT, and FHWA suggested the use of a retro-reflectometer for the evaluation of beaded pavement markings. Studies conducted by the FHWA concerning retro-reflectometers were also reviewed. The three presently available 30-meter geometry retro-reflectometers that were evaluated were the LTL-2000, the MX30, and the MP-30. It was determined that any of the 30-meter geometry retro-reflectometers evaluated would be sufficient. The LTL-2000, which has an accuracy of ±5%, was chosen because of its traceability to a reference standard in Denmark. None of the other 30-meter geometry retro-reflectometers evaluated were traceable to a reference standard.

The limitation of a hand-held retro-reflectometer is that it only takes one reading at a time. It is very labor intensive for very large or very long lines, such as runway centerlines and threshold lines. It only tests small sections of the marking area and not a composite of the marking as a whole. While the data collected can be stored, it still needs to be reformatted, averaged, and graphed. The inspection still contains a degree of subjectivity and user interpretation.

For the chromaticity or color check, the BYK Gardner Color-Guide 45º/0º spectrophotometer was used in conjunction with a CIE D_{65} chart. This device will show if the paint is fading. The data points are graphed on the CIE D_{65} chart, then checked to see if they fall within the ICAO white region or the FAA in-service aviation yellow region. If they fall on the correct side, in other words, white in the white region and yellow in the FAA in-service aviation yellow region, then they are considered to have passed. The luminance factor (reflectance) component Y should also be evaluated. The component Y is the absolute measure of the visual luminance of the source. The range of Y for yellow is 14.62-48.94 mnm and for white 28.65-85.51 mnm. If the data point does not meet the chromaticity coordinates (x, y) and luminance factor (reflectance) (Y), then the data point is considered to have failed. See figures A-1 and A-2 in appendix A.

For paint coverage, a transparent grid was fabricated. The grid concept was taken from the Air Force who used it for measuring rubber coverage on pavement. The grid can be 10 x 10 inches or 5 x 20 inches, each having 100 1-inch squares. The transparent grid is placed on a pavement marking, and the squares without paint are counted. This will give the percent of squares without paint. The paint marking coverage should be 50% or higher. Anything below this, the pavement marking becomes difficult to discern.

AUTOMATED METHOD.

The automated method is a much quicker and time-efficient method, but it carries a higher cost and a lower degree of accuracy than the manual method. A van-mounted Laserlux or similar mobile unit was used. The data collection is automated such that the averaging and graphing of the data is done by the computer onboard the mobile unit can be printed out. Also, while collecting the data, the van-mounted Laserlux takes a video of the pavement markings so that immediate results can be shown if a line passes or fails. The reports provided after the van-mounted Laserlux had collected the data were data reports and graphs for the retro-reflectivity (LTL-200) readings and data reports and graphs for the spectrophotometer (Color-Guide) readings.

THRESHOLD LIMITS.

The threshold limits for yellow and white pavement markings were determined to be 70 mcd/m^2/lx for yellow and 100 mcd/m^2/lx for white. At this level of retro-reflectivity, the eye cannot distinguish differences in the reflectivity on the pavement marking, but the retro-reflectometer can, giving the inspector a cutoff point to fail a line along with supporting documentation. This will establish a threshold limit for which the airport will be held accountable.

Since these limits are so minimal, it is suggested that additional field studies be conducted with actual airport inspectors under varying airport conditions. This additional data can be used to refine the actual pass/fail limits.

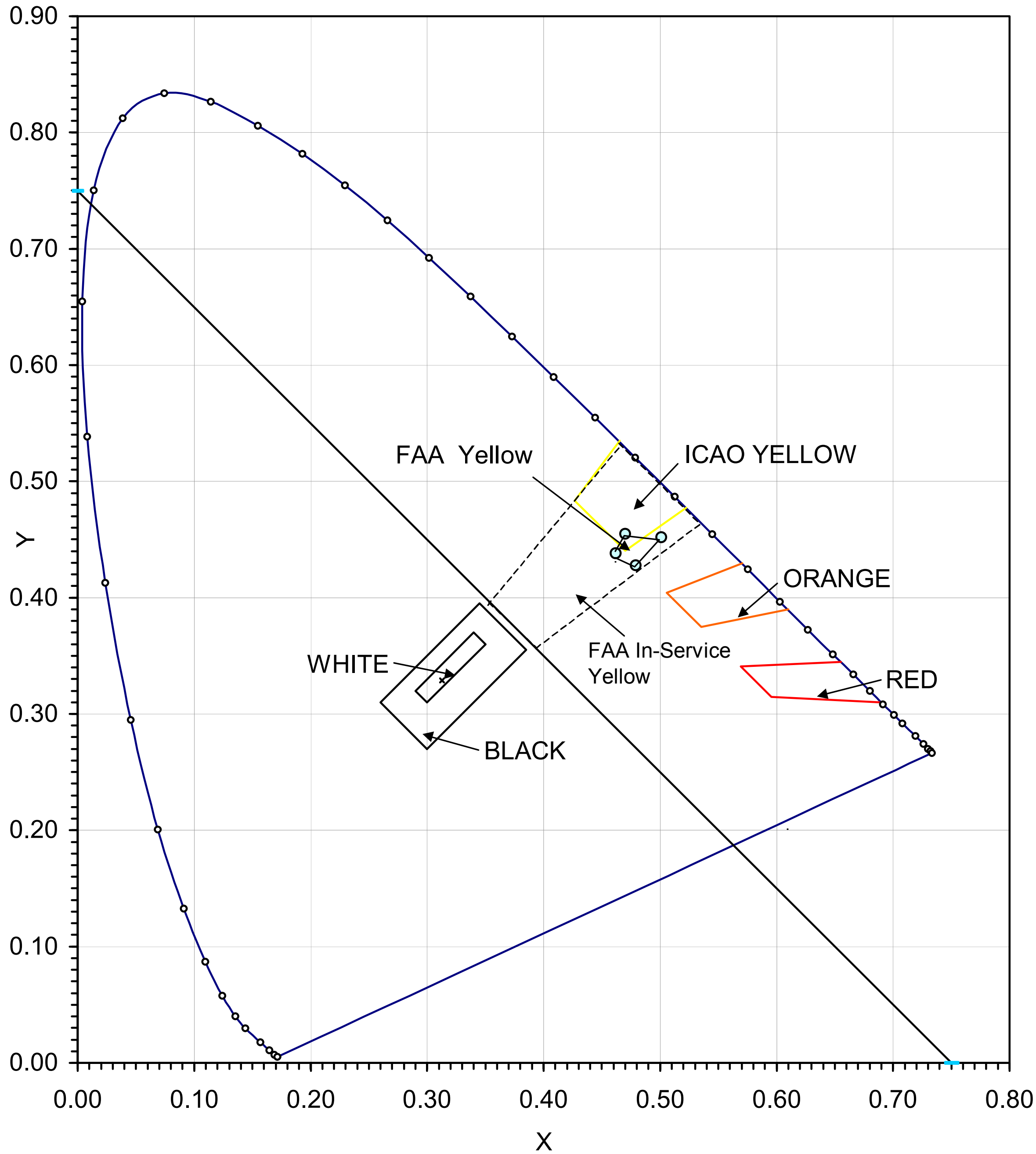


FIGURE A-1. ORDINARY COLORS FOR SURFACE MARKINGS

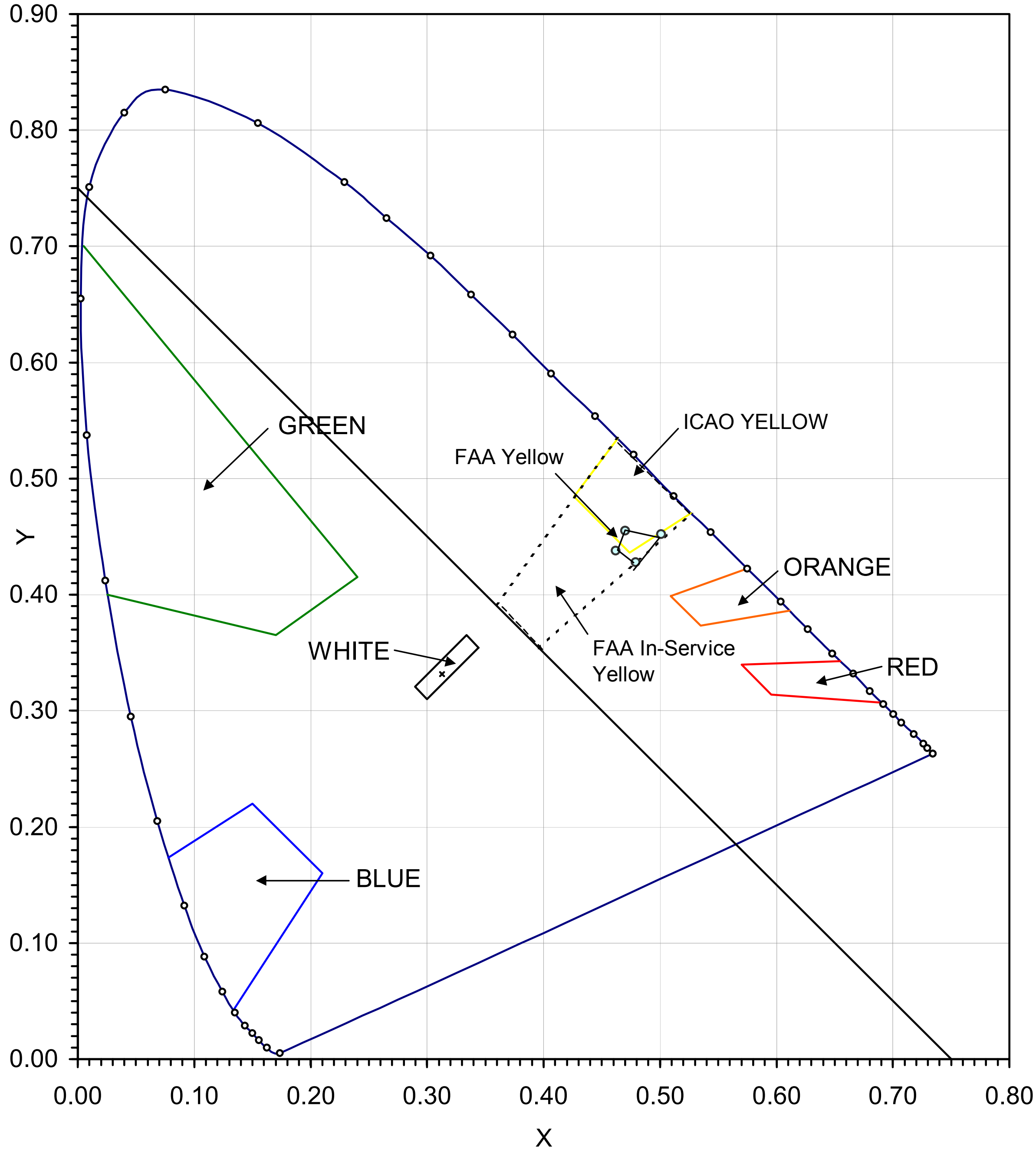


FIGURE A-2. COLORS OF RETRO-REFLECTING MATERIALS FOR SURFACE MARKINGS

Location	Area 7
Direction	West
Line	White Center 2
File	25T03C00.3L0

Video Chainage *	Average RL
0.0189	147
0.0379	195
0.0568	162
0.0758	199
0.0947	140
0.1136	146
0.1326	101
0.1515	151
0.1705	192
0.1894	117
0.2083	104
0.2273	85
0.2462	76
0.2652	60
0.2841	70
0.3030	112
0.3220	74
0.3409	90
0.3599	103
0.3788	90
0.3977	115
0.4167	190
0.4356	147
0.4546	100
0.4735	60
0.4924	103
0.5114	100
0.5303	168
0.5493	137
0.5682	129
0.5871	186
0.6061	143
0.6250	123
0.6440	94
0.6629	147
0.6818	190
0.7008	161
0.7197	72
0.7387	92
0.7576	76
0.7765	67
0.7955	153
0.8144	65
0.8334	81
0.8523	53
0.8712	71
0.8902	51
0.9091	65
0.9281	114
0.9470	123
0.9659	177
0.9849	93
1.0038	231
1.0228	86
1.0417	137
1.0606	122
1.0796	129
1.0985	145
1.1175	144
1.1364	128

FIGURE A-3. DATA FOR CENTERLINE ON RUNWAY 13/31 AREA 7 WEST

Video Chainage *	Average RL
1.1743	126
1.1932	103
1.2311	83
1.2500	102
1.2690	99
1.2879	89
1.3069	83
1.3258	111
1.3447	157
1.3637	126
1.3826	141
1.4016	72
1.4205	79
1.4394	71
1.4584	101
1.4773	102
1.4963	141
1.5152	136
1.5341	105
1.5531	161
1.5720	98
1.5910	172
1.6099	127
1.6288	252
1.6478	237
1.6667	192
1.6857	129
1.7046	249
1.7235	314
1.7425	282
1.7614	316
1.7804	260
RI Average	**128**

* The video chainage is distance travel which coincides with the video camera distance on the film footage provided with the van-mounted Laserlux evaluation.

FIGURE A-3. DATA FOR CENTERLINE ON RUNWAY 13/31 AREA 7 WEST (Continued)

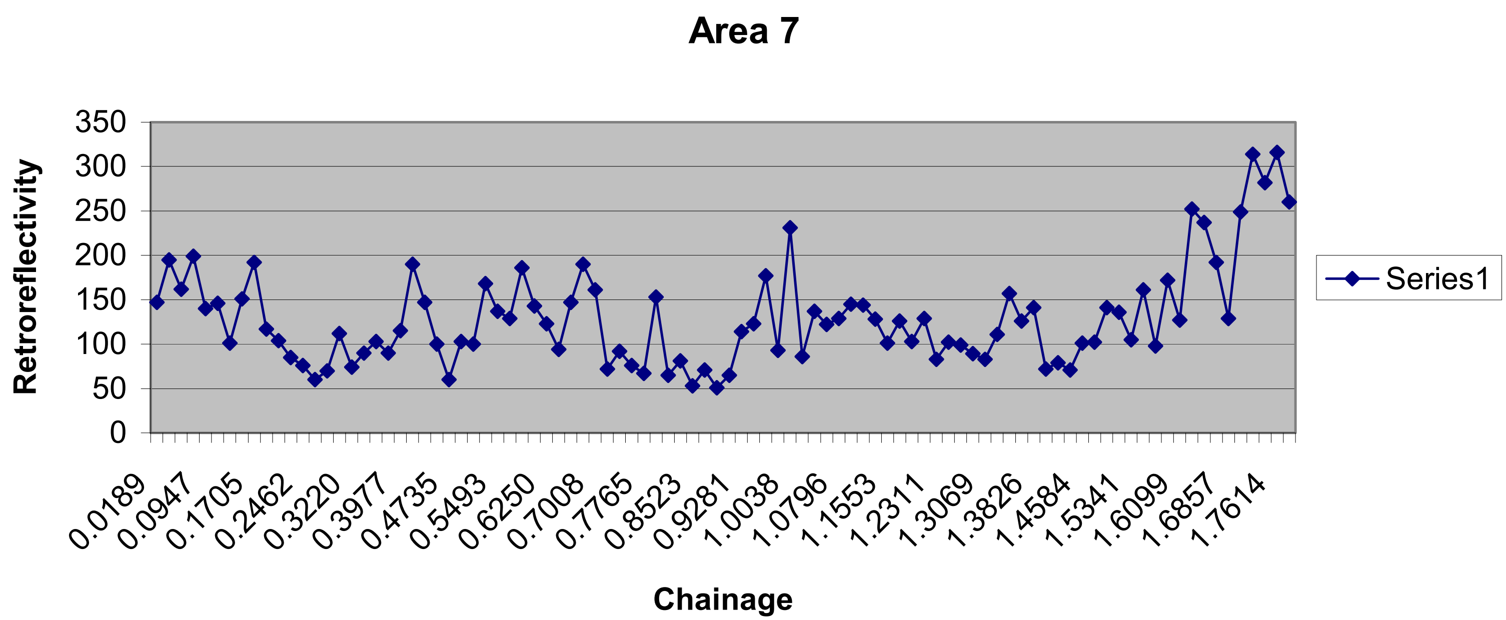


FIGURE A-4. GRAPH FOR THRESHOLD LINES ON RUNWAY 13/31, AREA 7

Ordinary colors for markings and externally illuminated signs and panels (figure A-1).

CIE D_{65} equations for ICAO yellow and white regions.

Yellow Region	
Orange boundary	y = 0.108 + 0.707x
White boundary	y = 0.910 - x
Green boundary	y = 1.35x – 0.093
Luminance factor	β = 0.45 (mnm)

White Region	
Purple boundary	y = 0.010 + x
Blue boundary	y = 0.610 – x
Green boundary	y = 0.030 + x
Yellow boundary	y = 0.710 – x

For colors of retro-reflective materials for markings, signs, and panels (figure A-2).

CIE D_{65} equations for ICAO yellow and white regions

Yellow Region	
Orange boundary	y = 0.160 + 0.540x
White boundary	y = 0.910 – x
Green boundary	y = 1.35x - 0.093
Luminance factor	β = 0.16 (mnm)

White Region	
Purple boundary	y = x
Blue boundary	y = 0.610 – x
Green boundary	y = 0.040 + x
Yellow boundary	y = 0.710 – x
Luminance factor	β = 0.27 (mnm)

For figures A-1 and A-2, respectively, ordinary colors for markings and externally illuminated signs and panels and colors of retro-reflective materials for markings, signs, and panels. The equations for the yellow boundary and yellow region, white boundary and the white region, are the same as shown on the next page.

FIGURE A-5. EXPLANATION OF FAA YELLOW BOUNDARY

Yellow Region:
white boundary $y = 0.910 - x$
White Region:
yellow boundary $y = 0.710 - x$

The shades of white and yellow were also charted from the Federal Standard 595B Colors. The shades charted were 33434, 33695, 33275, 33696, 33637, 33655, and 33538.

The CIE D_{65} charts in figures A-1 and A-2 show the yellow boundary limits for ICAO yellow and the FAA aviation yellow. The four data points for the FAA aviation yellow were obtained from AC 150/5370-10A page 226. The x and y values are consistent with the Federal Hegman yellow color standard chart for traffic yellow standard 33538.

Looking more closely at the equation for the white boundary $y = 0.910 - x$.
When $x = 0$ $y = 0.910$
when $y = 0$, then $x = 0.910$

For the yellow boundary $y = 0.710 - x$.
When $x = 0$ $y = 0.710$
when $y = 0$ then $x = 0.710$.

Drawing a line up through the data points (figure A-1) that are yellow on one side and white on the other, the line can be represented by the equation $y = 0.750 - x$. Where $x = 0$, $y = 0.750$, and $y = 0$, then $x = 0.750$. For the two dashed lines, the equation for the green boundary of the ICAO yellow, $y = 1.35X - 0.093$, was extended to the line $y = 0.750 - x$ with a dashed line. The orange boundary of the ICAO yellow was extended with a dashed line from $x = 0.5266$ $y = 0.4701$ through data point $x = 0.479$ $y = 0.428$. This designates the FAA in-service aviation yellow region.

Due to the three-dimensional aspect of color, when a line turns very dark brown or black, the CIE D_{65} chart does not work very well since it only represents two dimensions. Therefore, the inspector will need to look at the luminance factor (reflectance) component Y, which is an absolute measure of the visual luminance of the source. The range of Y for yellow is 14.62 - 48.94 mnm and for white 28.65 - 85.51 mnm. These were obtained by looking at the Y for the Q-panels and pavement marking readings, then taking the highest and lowest reading to obtain the range.

FIGURE A-5. EXPLANATION OF FAA YELLOW BOUNDARY (Continued)